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TREATMENT EFFICIENCIES OF SAND-BIOCHAR AND SAND FILTRATION SYSTEMS FOR HOUSEHOLD USE

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Abstract

This project focused on the comparative analysis of two household water filtration systems: a conventional sand filter and a hybrid sand-biochar filter. The aim was to develop cost-effective, scalable solutions capable of improving water quality by removing physical, chemical, and biological contaminants, thereby ensuring safer drinking water for domestic use. Filtration media included layers of gravel, coarse sand, fine sand, and a biochar layer produced from carbonized coconut shell agro-waste. The systems were constructed considering media layering and porosity to optimize contaminant removal. Water samples from river upstream, river downstream, and pond sources were treated and analyzed for key parameters including turbidity, pH, electrical conductivity, total dissolved solids, heavy metals (notably lead and iron), nitrate, phosphate, chemical oxygen demand (COD), and microbial indicators (E. coli and total coliforms). Laboratory results demonstrated that both filter systems significantly improved water quality; however, the sand-biochar filter exhibited superior performance, especially in the removal of heavy metals (achieving up to 91.1% lead removal against 26% for sand filter), turbidity (91.5% versus 80.3), and microbial contaminants (E. coli; 71.65% versus 64.76%). The biochar's high porosity and surface chemistry contributed to enhanced adsorption and antimicrobial effects, surpassing the traditional sand filter in critical

Key words: Biochar, filtration, contaminant, pollution, disinfection.

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contaminant reduction. Nonetheless, neither filter completely eliminated microbial pathogens to meet WHO standards, indicating the necessity of secondary disinfection such as boiling or solar disinfection. Dissolved solids and nitrate removal were limited by both systems. The study concludes that integrating biochar into sand filtration substantially enhances water purification efficacy, making the sand-biochar filter a more effective, sustainable, and affordable option for domestic water treatment in resource-limited settings. Recommendations include promoting sand-biochar filters for household use and incorporating additional disinfection steps to ensure microbiological safety.

Introduction

Water is arguably the basic life requirement in both humans and animals and is vital for preservation of the modern world (Gupta. et al, 1992). On the other hand, water pollution is the biggest challenge facing the world and causing the destruction of water resources around the world especially in rural settings where water sources like river, pond, and shallow wells are mostly exploited for household use. This is because of its pollution with solid waste, chemicals, leakage of sewage lines, the absence of these lines or surface runoff. Furthermore, human activities such as discharging waste into rivers has changed the water flow patterns in rivers in terms of quantity, quality and flow times. Changing flow quantities can affect water quality significantly. (Clasen et al, 2003). This led to a decrease in water quality due to an increase in the concentration of fluoride above normal levels causing disease in bones and teeth. These problems have led to a lack of safe drinking water for more than a third of the world population (EPA, 2023). Among the most widely promoted and studied Point-of-Use (POU) water treatment technologies is the sand filter, utilizing a container filled with layers of sand and gravel (Sobsey et al., 2008). Families can construct sand filters locally and inexpensively. Drinking water purification system should give final effluent water in line with the World Health Organization's (WHO) guidelines for drinking water quality. (Lee, He, 2006), have investigated the use of small-scale decentralized sand filtration units for household use. Performance of conventional sand filters is often limited in its removal of dissolved contaminants, including certain viruses, nutrients (like nitrate and phosphate), and chemical pollutants (Burch & Thomas, 1998). This limitation can be made better by integrating locally available and high-performance adsorbent materials like biochar. Biochar is a porous, solid material made by thermochemically converting agro-waste biomass in an oxygen-depleted atmosphere (Inyang and Dickenson, 2015). It is characterized by high internal surface area and microporous structure, with capacity to adsorb a wide spectrum of contaminants, including heavy metals, organic pollutants, and

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nutrients (Ahmad et al., 2014). The integration of biochar into a sand filtration system presents a potential powerful combination. This study concerns the incorporation of a coconut shell biochar into a sand filter for a comparative analysis of its performance to the conventional sand filters for household

Despite the abundance of water sources, the quality of available water is often compromised by several contaminants which pose serious health risk (WH, 2021). Conventional water treatment methods may be costly, labor-intensive and complex. There is therefore an urgent need for a water filtration system tailored specifically for domestic use that addresses these challenges. It is upon this premix that this work has set out to address by providing a cost-effective alternative.

Significant research gaps remain in translating these findings to real-world household water sources Also, this hybrid has the potential to create a more robust and multi-barrier point of use (POU) treatment system, enhancing the removal of both particulate and dissolved pollutants beyond what either medium could achieve independently.

Materials collection and preparation.

Sand of two different particle sizes were used; Coarse sand of size 0.75-1.00mm, and Fine sand of size 0. 3-0.5mm (plate 1 and 2) were collected from Farin-gada river Jos in a sack and was sundried to disinfect, it was sieved to achieve both the particle sizes and sun dried.





Plate 1: Sand (0.3-0.5mm particle size). **Plate 2:** Sand (0.75-1.00mm particle size

20.05kg. of gravel was collected in a sack, weighed a sieved to attain particle grain size from 510mm.

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Plate 3: Gravel (5-10mm particle size)



Plate 4: Coconut shell charcoal

Biochar preparation:

A 11.97kg of coconut shell was collected from a coconut seller at Farin gada market it was then washed and sun-dried to remove moisture. This was carbonized at a temperature of 550°c to obtain a charcoal that weigh 3.14kg which was, sieved to remove dust.

Container construction.

The container was constructed with a transparent glass for a clear view Container dimension in accordance with CAWST sand filter manual, 2008). The filters are constructed in layers from bottom to top, The biochar layer doesn't depend on its thickness to efficiently function but on the amount of microscopic porous structure and its large internal surface area for effective adsorption function. As water passes over the vast surface area of the carbon, the contaminants are quickly grabbed and held. The coarse layer is for pre-filtration to trap some larger impurities and suspended solids while the gravel is for physical support. The set up is as seen in plate 5 and 6 below.



Plate 5: Sand-biochar filter layering



Plate 6: Pure sand filter layering

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Raw water samples collection

Raw water samples were collected using composite method in the morning from upstream and downstream sides of Delimi river and farin-gada river at a distance 288m apart respectively. In each case, two samples were collected at 2.7m apart in clean containers and mixed to get representative samples.

The second raw water was collected from the pond opposite the university of Jos permanent site gate using grab sampling method. Figure. 7 below shows the sample collection points.

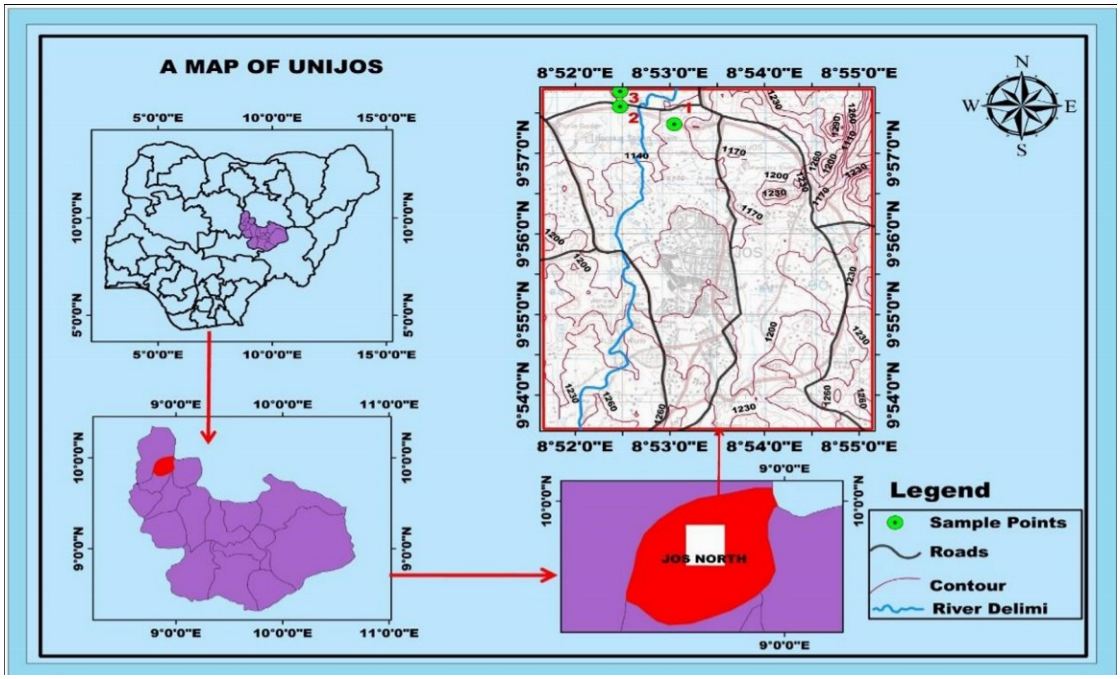

Figure 7: shows the water sample collection points.

Determining the pH, temperature, electric conductivity and total dissolved solid of the water samples were determined using Hanna instrument HI 9813-5

Turbidity: The DR/890 Colorimeter this device was operated according to standard method to determine the turbidity in FTU and the colour in FAU respectively. The same instrument was used to determine the phosphate in the water samples except for the difference in the respective entry numbers. The chemical oxygen demand (COD) was determined using $KMnO_4$ (potassium permanganate) solution by titration. the relationship stated below was then applied;

COD = [redacted]

Where: a = consumption; b = blank; V = volume of sample; F = titration factor

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Total coliform and E. coli was determined using a media; McConkey Agar, where the sample was prepared and autoclaved to eventually count the colonies after incubation.

To determine nitrate, three (3) sample tubes were setup in the rack to handle reagent blank, The tubes were evenly spaced throughout the rack to allow for the even flow of bath water between the tubes. After placing the set up in a 100°c heated water for 25minutes, the absorbance was read using the UV-Vis spectrophotometer and calculated using the relation;

N = - 2.09 × absorption + 7.82.

Chloride concentration was determined using the relation;

Cl = [redacted]; Where: a = ml of consumption; b = blank; N = normality of $AgNO_3$,

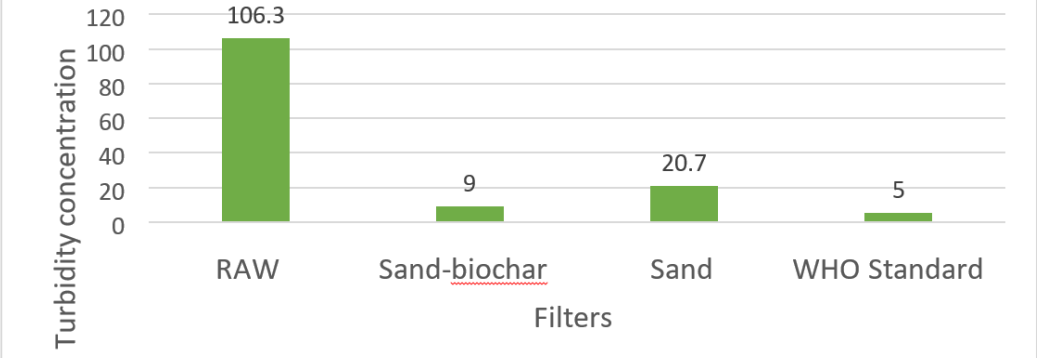
Water Quality Parameters Analysis of Results

Water quality parameters are anlysed to ascertain whether or not they meet the World Health Organization (WHO) and the Nigerian standard for drinking water quality (NSDWQ).

Turbidity (NTU). The raw water sample analyzed reveals initial turbidity of 106.3 NTU, this indicates very cloudy water, due to a high load of suspended solids like silt, clay, organic matter, and micro-organisms.

Both filters drastically reduce turbidity, but neither of it meets the 5 NTU standard. The SandBiochar filter reduced the turbidity to 9 NTU being a 91.5% reduction which is a better performance than the sand filter with 20.7 NTU being 80.53%. Biochar's porous structure is more effective at trapping fine particles. High turbidity can interfere with disinfection and harbor pathogens as shown in figure 1 below.

Figure 4.1: Compliance of Turbidity (NTU) to WHO/NSDWQ



Total dissolved solid (mg/l):

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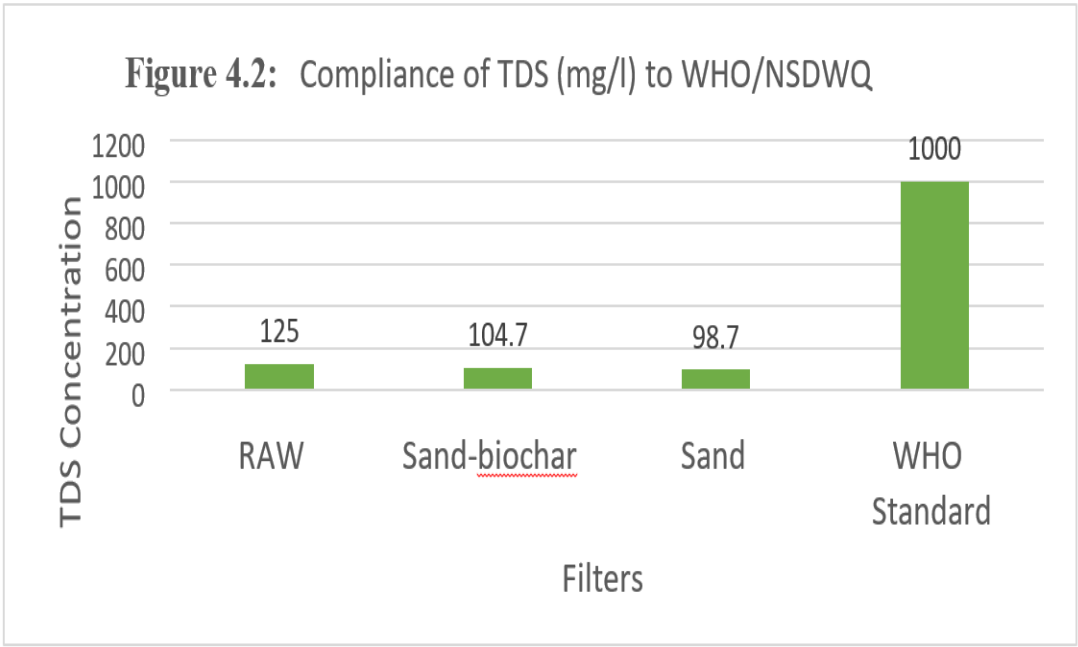
TDS represents the total concentration of inorganic salts (e.g., calcium, magnesium, sodium, bicarbonates) the WHO recommends a value <1000 mg/l. High TDS (>1000 mg/l) can cause excessive scaling in pipes and appliances, and give water a mineral-like or salty taste, potentially leading to reduced water consumption. The health effects are primarily related to the specific minerals present e.g., sodium for hypertensive individuals rather than TDS itself.

Both filters show a minor reduction in TDS. The changes are not significant as these dissolved minerals are not effectively removed by physical filtration or adsorption alone. Both filters reduce TDS from 124 mg/l to 101-107 mg/l.

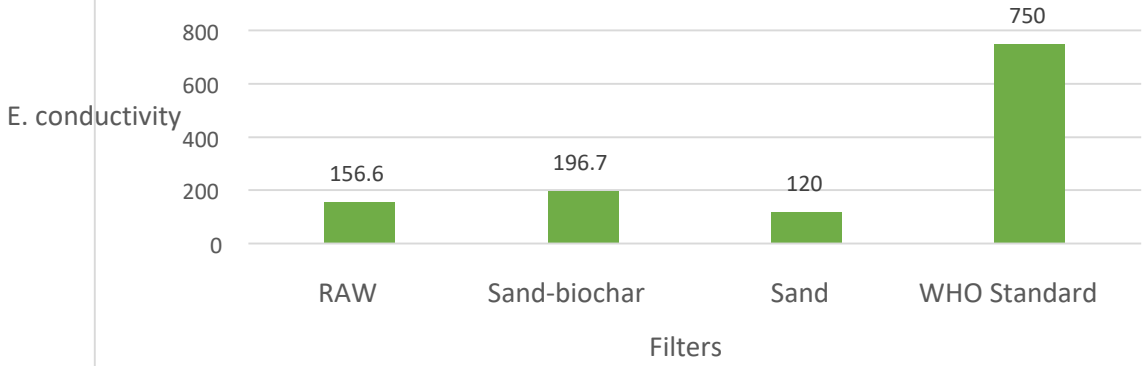
Neither filter is designed for significant demineralization. The observed slight reductions are likely due to the removal of suspended solids that contribute to TDS. This is acceptable for the stated domestic purpose, as the raw water's TDS is well within safe limits



E. Conductivity (µs/cm):

Figure 2 shows the performance of sand biochar and sand filter where the sand filter performed better than the sand biochar, however both treatment medium is well within the WHO standard. values are well below the 1000 mg/l limit, indicating low total dissolved solids.

Figure .3: Compliance of E/conductivity (µs/cm) to WHO/NSDWQ

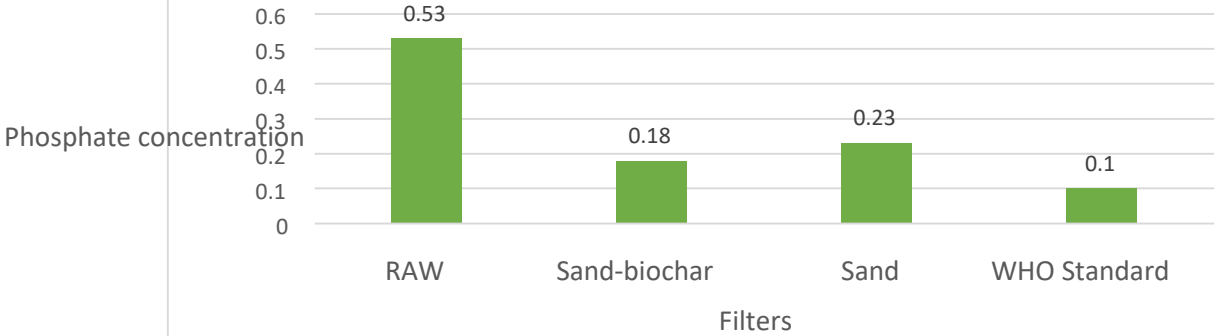


All values are within the acceptable range. Conductivity correlates with TDS, confirming the low ionic content of the water. The higher value for Sand-Biochar could be due to the release of some minerals from the biochar itself. If the biochar contains unburnt or partially burnt nutrient content or electrolytes like potassium (k^+), calcium (Ca^{2+}) and sodium (Na^+) that might not have been completely broken down by the pyrolysis, these nutrients dissolved into the water, increasing conductivity. The pyrolysis did not completely burnout this nutrient hence it contributed to the increase in electrical conductivity.

The raw water is slightly acidic but within range. Both treatment methods brought the pH to a neutral level, which is ideal and prevents corrosion or scaling in pipes.

Phosphate PO4 (mg/l)

Figure 4.5: Compliance of Phosphate PO4 (mg/l) to WHO/NSDWQ



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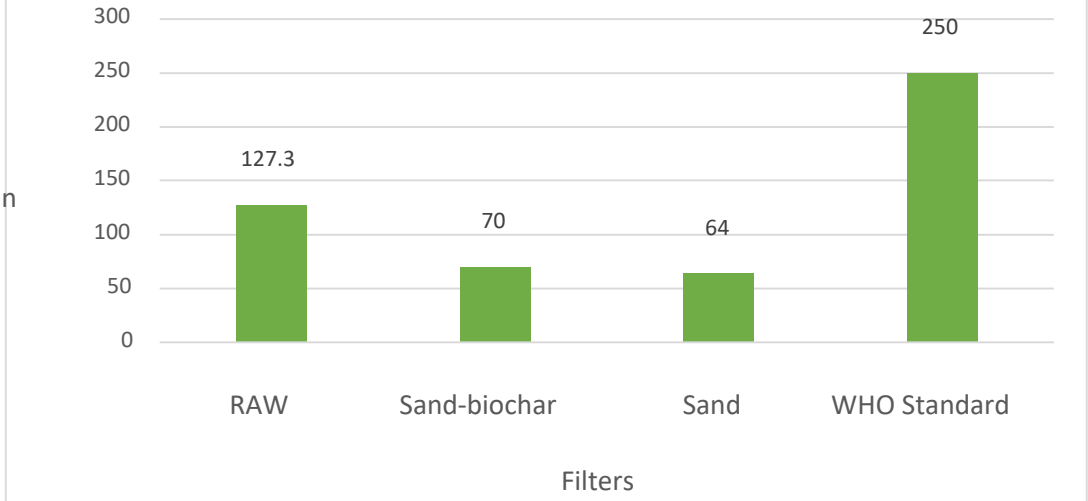
The raw water significantly exceeds the standard. This is a strong indicator of contamination from fertilizers, sewage, or detergents. Both filters reduce phosphate effectively, but not enough to meet the strict 0.1 mg/l guideline. The Sand-Biochar filter performed best, due to adsorption onto the biochar surface and both substances reduce iron content, further improving aesthetic quality.

Figure 4.7: Compliance of chloride Cl (mg/l) to WHO/NSDWQ



All values are safe. High chloride can indicate sewage or industrial pollution, but levels here are acceptable.

Lead Pb (mg/l)

Raw water is highly toxic and non-compliant (7x the standard). Source is likely corroding lead pipes, plumbing fittings, or industrial effluent. Simple sand filtration is ineffective at removing dissolved heavy metals while Sand-biochar did comply with the strict 0.015 mg/l standard showing a key success. The biochar filter reduces lead to a compliant level (0.0063 mg/l) so it is effective at adsorbing heavy metals like lead due to its porous structure, and large surface area. This indicates that biochar significantly adsorbs heavy metals, and high porosity, which facilitate heavy metal binding.

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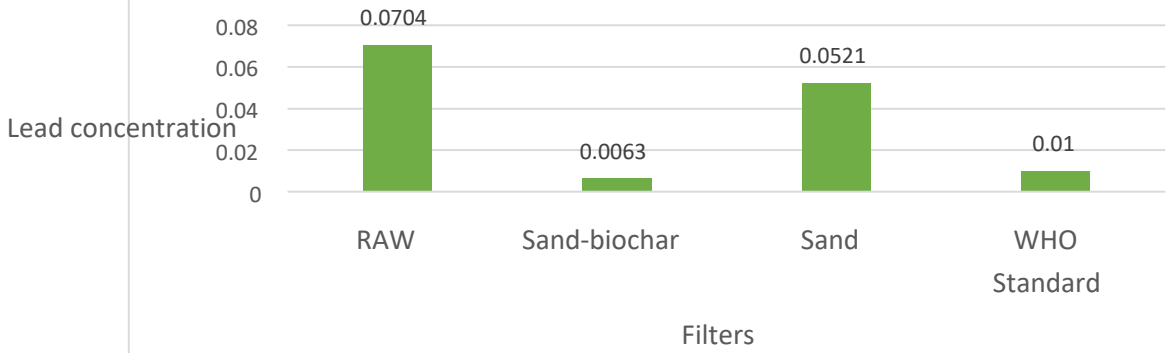
Figure 4.8 : Compliance of lead Pb (mg/l) to WHO/NSDWQ

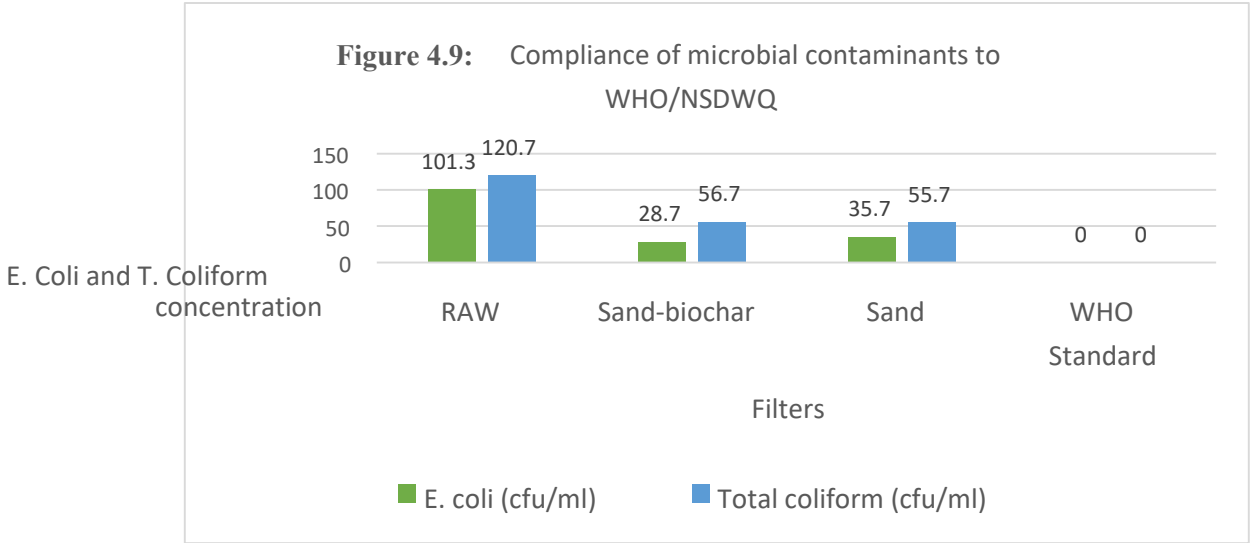


The presence of E. coli (101.3 cfu/ml) in the raw water is a direct confirmation of recent fecal contamination, likely from human or animal waste. This is a major health risk. Both filters reduce E. coli counts significantly by 71.65% and 64.76% in the respective cases. Filtration alone is insufficient for complete disinfection it requires chemical treatment to deal effectively fecal contamination.

High total coliform count confirms general microbiological contamination in the raw water, which includes bacteria from soil, vegetation, and feces. Similarly, E. coli counts are reduced by about 50% in the filters but not eliminated.

The evaluation reveals that both filters improve water quality compared to raw water, but they differ in their contamination removal efficiencies.

Figure 4.9: Compliance of microbial contaminants to WHO/NSDWQ



Heavy Metal Removal: Lead and iron removal is higher in the sand-biochar filter with a removal efficiency of 91.10% and 75.54%, compared to only 26.00% and 72.38% in the sand

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filter. This indicates that biochar significantly adsorbs heavy metals, likely owing to its surface charge, and high porosity, which facilitate heavy metal binding.

Dissolved Solids and Chemical Parameters: The sand filter shows slightly better removal efficiencies for parameters like TDS, conductivity, nitrate, phosphate, and chloride, with the highest being 21% for TDS and 49.73% for chloride. This suggests that the sand-only filter is relatively more effective at reducing dissolved solids, potentially due to physicochemical interactions, although the overall reduction percentages are modest.

Analysis of Parameters

For parameters directly associated with water safety and quality, lead, E. coli, and turbidity are crucial. Here, the sand-biochar filter excels in removing these contaminants with significantly higher efficiencies. The iron removal rate is also higher in the biochar filter, which is beneficial for reducing aesthetic problems and corrosion potential. For parameters like TDS, the sand filter shows a slight edge, but both filters are moderately effective.

Identification of the Better Filter

Based on contamination removal efficiency which is critical for ensuring safe drinking water, the sand-biochar filter is superior; It demonstrates higher removal efficiencies for microbiological contaminants (E. coli and Total coliforms), Significantly better turbidity removal, Exceptional removal of heavy metals like lead and iron, good removal of nutrients like nitrate and phosphate.

Temperature

Temperature itself is not a direct health hazard; however, it is a master variable influencing other parameters. Elevated water temperature potentially leads to conditions that favor the growth of certain pathogens. It can also increase the rate of chemical reactions, potentially accelerating the corrosion of pipes, which can release metals like lead (Pb) and iron (Fe) into the water (WHO, 2017). The temperature of the raw water is consistent, suggesting a stable source, but the filtration process does not significantly alter it, which is expected.

The raw water pH is generally within the acceptable range. The filters caused minor fluctuations but do not drastically alter pH, which is expected and acceptable.

Turbid water shields microorganism (harmful bacteria, viruses, and parasites) as well as promote bacterial growth by providing them with nutrients and habitats through sediments. It is also an indicator of runoff or waste water. The Sand-Biochar filter has consistently out-performed the Sand filter in reducing turbidity.

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Nitrate concentration in water is an indicator of the result of human activities such as agricultural runoff, failing septic tank and wastewater, high level of nitrate >50mg/l as recommended by WHO are dangerous especially to infants causing a reduced blood oxygen carrying capacity as nitrate is converted to nitrite in the body. Nitrite binds to hemoglobin, forming methemoglobin, which cannot carry oxygen. This can lead to life-threatening oxygen deprivation and can also cause cancer in the occasion of long-term ingestion.

Both filters show limited effectiveness in removing nitrates. Concentrations in filtered water are often similar to or only slightly lower than raw water.

Phosphates are not considered directly toxic to humans but excessive intake can disrupt the bodies calcium balance and accelerate aging and also heart attack. Both the filters didn't show significant performance in the reduction of phosphate.

Iron (fe) concentration of iron in the water when high causes a metallic taste, bad odors, and reddish-brown staining and iron overload which leads to fatigue, joint pain, and damage to the liver, heart and pancreas. Both filters are effective at removing iron, but Sand-biochar filter is often superior. Whereas calcium is a beneficial nutrient essential for bone and dental health. the levels present pose no health risk. Very high-level causes hardness which further causes scale formation and reduces the lathering of soap affecting its quality, usability, and effects on human body. Chloride in water has no direct health implication but when at high concentration (exceeding 250 mg/l) causes a salty taste in the water also highly corrosive to house hold appliances like plumbing fixtures and metal pipe potentially leading to leaching of toxic metals such as lead and copper into water supplies. The concentration of chloride in the raw water is compliant to the WHO standard, so also the filtered water from both filters though the level of reduction is minimal.

Lead is a potent neurotoxin. This is a critical health concern. There is no safe level of exposure as WHO have set a Maximum Contaminant Level Goal (MCLG) of zero. Lead exposure causes reduced IQ, attention deficits, and learning disabilities. In adults, it can cause cardiovascular effects, increased blood pressure, and kidney damage (WHO, 2019). The presence of lead indicates corrosion of plumbing materials. The Sand-Biochar filter demonstrates exceptional lead removal.

Water with high COD causes rapid decomposition which consumes dissolved oxygen causing depletion and hence causes harm to aquatic life. Both filters are highly effective at reducing COD, indicating good removal of organic pollutants. The Sand system is more effective at removing organic matter, this improves water quality and reduces the potential for bacterial regrowth

E. coli in water suggests possible contamination by pathogens that may lead to gastrointestinal illness such as diarrhea and vomiting and fever. The results are variable

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and highlight a critical limitation of simple filtration. Sand-biochar filter reduces E. coli significantly. This suggests a filter breakthrough or the influence of other factors like high turbidity in the influent, but fecal contamination indicator shows none compliance with the WHO standards.

Total coliforms are a large group of related bacteria commonly found in the environment, including soil, vegetation, and water, as well as in the intestines of warm-blooded animals. They are generally not harmful themselves but are used as indicators of quality because their presence signals potential contamination by pathogenic organisms or a breach in water treatment or distribution system. Just like E. coli, there is no room for total coliforms in water provided by WHO, where in our observed values from the lab analysis, the values from the raw water are high but reduce slightly after filtration but still didn't meet up with the standards as well.

Conclusion

The finding reveals that the Sand-Biochar filter was exceptionally effective in removing heavy metals, especially lead, turbidity, iron, and phosphate compared to the sand filter. It is also effective pathogen reduction, where E. coli and Total Coliforms Both filters showed limited effectiveness in reducing dissolved ions. as evidenced by the minor changes in TDS), EC), Turbidity, Phosphate and Nitrate levels. The Sand-Biochar filter is identified as the more effective and advantageous filtration system for improving water safety, particularly in settings where protection from toxic heavy metals.

The Sand-Biochar filter is recommended for household and community-level water treatment, especially in areas with suspected heavy metal, lead and iron contamination in water sources.

It is however recommended that the filtered water undergo a secondary disinfection by undertaking pre-treatment of biochar: and multi-stage filtration.

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